Cautionary Tales Part XVIII

<u>Tensile and Torsional Modulus</u>

In the Gold Star quiz in this edition there are likely to be questions about the modulus of spring materials, so I hope that this article does not contradict the correct answer. Spring designers know that the tensile modulus (sometimes called Young's Modulus or the modulus of elasticity) is a value they look up and use in calculating a spring stressed in bending. Similarly, spring designers know that the torsional modulus (sometimes called the rigidity or shear modulus) is a constant used in calculating a spring stressed in torsion. The modulus of most spring materials may be regarded as a constant in most circumstances, but the moral of this cautionary tale is to point out when a constant is not a constant!

Even the name of these moduli (the plural of modulus) is not constant, but please be assured that the alternative names given above are just that. Young's Modulus is the same as the "modulus of elasticity" and the "tensile modulus". Similarly, the rigidity modulus is the same as the "shear modulus" and the "torsional modulus". These names are synonyms designed only to confuse the unwary, or those that haven't read this column. The tensile modulus may be calculated from the slope of a tensile test plot of stress vs. strain in the elastic region where the graph is a straight line. This property is often described, very helpfully, as the stiffness of a spring material, in the same way as the rate is the stiffness of a spring – the slope of the straight line plot of load vs. deflection in the regime where Hooke's law applies.

So, apart from the name, you might consider these moduli to be constants that cannot be changed by anything a spring manufacturer does to the wire or strip material during his manufacturing processes. For most materials, at a given temperature, this is correct. It has been supposed that the modulus changes when spring steel is converted from its soft state (i.e. with a structure of carbides in ferrite) to hardened state either by harden and temper or austemper, but this not the case. The modulus of soft spring steel is almost the same as that of the same steel in the spring hard condition, and this is because the modulus is only dependent upon the atomic forces between the atoms in the crystal structure of the metal. The crystal structure of carbon or low alloy spring steel is, to a first approximation, body centred cubic whether the steel is soft or hard. However, although the modulus values are a constant at room temperature, this is not reflected in the published, or generally accepted and used, values in each country. The following table illustrates these differences, which have been brought to *IST*'s attention recently, because of the use of our version 7 CAD programs that allow you to switch your design from BS to DIN to EN to ASTM materials. The same spring design appears to give different loads depending on the modulus in use in each set of material standards, and some spring manufacturers have, quite understandably, enquired why *IST*'s programs show this illogical result –here's the explanation.

	BS	DIN or EN		ASTM
	As drawn MPa (psi)	As drawn MPa (psi)	After LTHT MPa (psi)	As drawn MPa (psi)
Tensile modulus				
Patented carbon	206800 ($30x10^6$)	206000 ($29.9x10^6$)	-	207000 ($30x10^6$)
OHT carbon & alloy	206800 ($30x10^6$)	206000 ($29.9x10^6$)	-	207000 ($30x10^6$)
302 stainless	187500 ($27x10^6$)	180000 ($26.1x10^6$)	185000 ($26.8x10^6$)	193000 ($28x10^6$)
Torsional modulus				
Patented carbon	79300 ($11.5x10^6$)	81500 ($11.8x10^6$)	-	79300 ($11.5x10^6$)
OHT carbon & alloy	79300 ($11.5x10^6$)	79500 ($11.5x10^6$)	-	79300 ($11.5x10^6$)
302 stainless	70300 ($10.2x10^6$)	70000 ($10.2x10^6$)	73000 ($10.6x10^6$)	69000 ($10.0x10^6$)

One qualification of the conditions under which a modulus is constant is necessary. As temperature is increased, it has the affect of reducing the modulus. Hence the load a spring will support at elevated temperatures is less than at room temperature and, conversely, at temperatures below zero the load a spring will support increases. The temperature coefficient for change of modulus is between 2% and 4% for every 100°C for most spring materials.

Finally, there is a spring material for which the modulus values are not a constant, and this is 302 stainless steel – the material with the greatest differences shown in the above table. The DIN values are different for before and after stress relief heat treatment, and this is correct. During an earlier cautionary tale (No. VIII), it was revealed that the crystal structure of spring hard 302 stainless steel changes to some extent from strained austenite to martensite during stress relief heat treatment, and this causes the modulus to increase. However, the increase depends on the strain present, the temperature and time used, and so it is impossible to quantify accurately the change that takes place, so it is not surprising that there are small differences in the accepted modulus values for this spring material. The actual modulus will vary from spring design to spring design.

Mark Hayes is the Senior Metallurgist at the Institute of Spring Technology (IST) in Sheffield, England. Hayes manages IST's European Research Projects, the spring failure analysis service, and all metallurgical aspects of advice and training courses given by the Institute.

Readers may contact him by telephone at (011) 44 114 2760771 or (011) 44 114 252 7984 (direct dial), fax (011) 44 114 2527997 or e-mail at m.hayes@ist.org.uk.